May 22, 1984
correction page 28
" 29

"AEROSPACE"

Symposium on Technological Frontiers and Foreign Relations
Sponsored by
National Academy of Sciences/National Academy of Engineering
with the Council on Foreign Relations, Incorporated

Hans Mark
National Aeronautics and Space Administration
Washington, D.C. 20546

(1) Historical Introduction

Aerospace is a peculiarly American enterprise. The basic ideas that made flight possible came from elsewhere but they were put into practice for the first time by Americans. In the early years of the 19th century, an Englishman, Sir George Cayley, made the intellectual breakthrough that made flight possible by recognizing that the lift forces provided by the wings of an aircraft and the thrust provided by the power plant should be treated separately. Equally in the case of reaction propulsion—or rocket motors—others, notably the Chinese, had developed useful rockets several centuries ago. An 18th century British military engineer, Colonel William Congreve, first developed useful military rockets. It is not clear whether they were ever decisive in war, but Congreve did provide Francis Scott Key the image for a line in a poem that later became our national anthem. "The Rocket's Red Glare" is familiar to all of us, and the line refers to real rockets used by the British in the attack on Fort McHenry in Baltimore Harbor in September 1814 during the War of 1812.

In spite of the pioneering done by others, Americans can rightly claim the two most important technical firsts, the achievement of powered flight in December 1903 by the Wright brothers and the flight of the first liquid fueled rocket by Robert Goddard on March 16, 1926. These two milestones formed the basis of American preeminence in aerospace technology and have continued to inspire succeeding generations.

It is equally important to understand that American leadership in aerospace depended on an institution that was established in 1917, the National Advisory

Committee for Aeronautics (NACA). Responding to the weakness of American military aviation during the First World War, the Congress created the Committee as part of the Naval Appropriations Bill of 1917. The Committee was empowered to conduct research in all of the scientific and technical areas important in aviation and was given the necessary resources to accomplish that objective. It is no exaggeration to say that the work done by the National Advisory Committee for Aeronautics and its successors has been crucial to the maintenance of American leadership in aerospace. The fact that an institution existed which made it possible for the United States to make consistent, long-term investments in research and in advanced technology development has made all the difference over the years. It is largely for this reason that the field of aerospace remains an American province.

(2) World War II

In the years between the World Wars, Americans continued to set the majority of technical records in the field of flight. The names of Lindbergh, Doolittle, Hughes, Post, Earhart and others immediately come to mind. There is no doubt that these people represented the technical superiority that was enjoyed by the United States during that period. In the field of rocketry, Robert Goddard built and flew the first liquid fueled rocket before the Germans started their MIRAK series of rocket flights at the Raketenflugplatz near Berlin. The Germans, under the leadership of Walter Dornberger and Wernher von Braun, although behind the work of Goddard in technical concept, quickly recovered the lead because they were better organized and had much clearer objectives. The basic ideas on which the liquid fueled rockets of Robert Goddard and Wernher von Braun were based are still used today in the development of propulsion systems for the Space Shuttle and for various military rockets. It is only this early work which has made what we are doing today possible (Reference 1).

In aeronautics, also, the work in the United States tended to be random and was not as well organized as it was elsewhere even though we enjoyed a technical lead. The Germans, through the influence of Hermann Goering, took the lead in organizing military aviation. The Luftwaffe was a feared weapon before a shot was fired in World War II. Particularly, this was due to a "disinformation" campaign carried out by the Germans which had particularly great influence on Charles Lindbergh who, in turn, tried to influence the foreign policy of the United States toward the Germans. The Luftwaffe was indeed a formidable weapon, but it turned out to be not formidable enough. The example of the Battle of Britain is the crucial case in point. The Germans always looked upon air power as support for land power and not really as an independent military arm. The Germans had some very good airplanes, but it is important to remember that they never built anything like the large, long-range bombers such as the Boeing B-17's, the Consolidated B-24's, and the Boeing B-29's that the United States eventually fielded. The Germans lost the Battle of Britain simply because they did not have the stragetic bombers to prevail. Their basic aircraft, the Heinkel HE-11's and the Junkers JU-88's, were good airplanes, but they were range limited and, therefore, the British could indeed operate many of their interceptor squadrons from air bases that the Germans could not reach.

At the beginning of World War II in 1939, the United States air services were relatively weak. Although a number of advanced aircraft were in development, they did not exist in quantity and were not ready for combat. However, because of the technological base provided by the National Advisory Committee for Aeronautics, the United States quickly caught up. President Roosevelt said in 1940 that we would build 50,000 aircraft, and I well remember that no one believed him. As it turned out, almost 250,000 airplanes were built in the United States during World War II, and this alone ranks as one of the foremost achievements in aeronautical technology. There is one important area in which the Germans stayed ahead during the entire course of the Second

World War and this is the field of military rocketry. If the technical tour de force of the allies during the Second World War was the creation of nuclear weapons, then the equivalent achievement on the German side was the creation of the first long-range rocket that had military applications, the V-2. While air power was very important during World War II, all the evidence indicates that it was not completely decisive. Both the V-2's and the nuclear weapons appeared too late in the war to have any real impact on the outcome. While it is true that the use of nuclear weapons shortened the war against Japan, they did not change the outcome of the war in a decisive fashion.

Air power, or more accurately, aerospace power came to dominate the post-war world primarily because nuclear weapons and long-range rockets were combined into what John von Neumann called intercontinental artillery. There is no doubt that today the employment of these weapons would indeed be the decisive factor in any conflict. It is no exaggeration to say that the strategic balance (or as some people call it, the balance of terror) that has existed for almost forty years has provided the framework within which the international politics of the post-war world have been conducted. It is, of course, the changing of this technological situation today that threatens to disturb the current balance with which many people have become comfortable. I will return to this point later on because it is perhaps the most important new development that we must take into account in structuring the foreign policy of the United States. However, before returning to this most important matter, some more history is necessary (Reference 2).

(3) Commercial Aviation (1925-1965)

The first commercial air services were established in the mid 1920's. They were based primarily on military aircraft that were developed during the First World War. The first air services were subsidized by the United States Government in the form of subsidies to the operators to carry mail. One can say that this is an early example of what the United States did to subsidize communications just as later COMSAT was subsidized to get the country into the communications satellite business. It was the early air mail services that grew into the great airlines of today. There was a time when TWA stood not for Trans World Airlines but Transcontinental and Western Airlines.

From a technical viewpoint, the most important area of subsidization by the government was in the field of propulsion. The great air-cooled radial engines that later powered most U.S. aircraft in World War II were developed for military purposes in the 1930's. As it turned out, such engines had the best horsepower to weight ratios, and their development was primarily due to a few farsighted people in the Army Air Corps, such as General H. H. Arnold, who foresaw the importance of strategic aviation. These engines were, of course, adapted for civilian use as well. The other important technical development was the creation of an all metal airplane. Only with all metal construction was it possible to develop airplanes that were both large enough and safe enough to be practical from a commercial viewpoint. All metal construction and efficient air-cooled engines were combined to create the famous Douglas DC-3 in 1935. The Douglas DC-3 really was the first successful commercial airliner in the world. Over 20,000 were built and it was the workhorse of the U.S. Army's and the Navy's transport fleet in World War II during which it was known as the C-47 in the Army and the R4-D in the Navy. Several thousand of these aircraft are still in service all over the world nearly fifty years after they were built.

The Douglas DC-3's, fine as they were, were still range limited because they were too small. Intercontinental travel by air before World War II depended primarily on the great seaplanes or flying boats operated by organizations such as Pan American Airlines. The technology for building large, land-based aircraft was not yet ready and so the first intercontinental airplanes were seaplanes.

Commercial aviation came into its own after 1945 when a generation of airplanes based on the great four-engine land-based bombers of World War II was created. These were the DC-6, the Douglas DC-7, the Lockheed Constellation, and the Boeing Strato-

Cruiser. Because of the operational experience gained in World War II, it was possible to calculate the operational economics of these airplanes precisely. Thus, these aircraft came to dominate commercial air travel and they did so until the early 1960's when large multi-engine jet aircraft replaced them. The creation of the large four-engine intercontinental transports resulted in the first large expansion of air travel in the decade after World War II. These airplanes were used by the United States but were also sold to other nations, and this was important not only economically but politically as well. The pattern established shortly after the war in the creation of the large four-engine propeller-driven transports was repeated when jet propelled transports were introduced in the early 1960's.

(4) The Jet Age

Just as the great radial reciprocrating engines led to the development of air power in World War II, another innovation in propulsion created a new revolution in aviation. This was the jet turbine engine. Turbine engines were a European development initiated by an Englishman, Sir Frank Whittle, who was granted a patent on the jet turbine engine in 1930. It was a technical development deemed to be necessary if aircraft were ever to be made to fly at speeds exceeding the speed of sound. Whittle and his collaborators in England were the first to work out the principle and then to build and test a working jet turbine engine in 1937. Work started on jet propulsion in Germany as well with the first patent granted in 1935 to Hans von Ohain. The German work proceeded more rapidly and the first flight of a jet powered aircraft, the Heinkel HE-178, was conducted in August 1939, almost two years before a Gloster E28/39, powered by one of Whittle's engines, flew on May 15, 1941. The first operational jet airplane was the Messerschmitt ME-262 interceptor which was fielded by the Germans in the waning days of World War II.

At the end of World War II, the United States decided to build large multi-engine jet bombers designed to carry the atomic weapons that would eventually lead to what we today call the nuclear strategic balance. These aircraft were intended to be the Strategic Air Force which is still in existence today as the U.S. Air Force Strategic Air Command. There were formidable technical challenges that had to be overcome to build the large jet bombers. The first was to get jet engines to operate reliably, and this meant that problems in high temperature materials and internal aerodynamics had to be solved. It was also necessary to create the large flexible all metal structures which would be designed to operate in an environment where the airplane is flying just below the speed of sound. This was also accomplished, and the Boeing B-47, the first intercontinental all jet bomber, was put into operation two years after the end of the war in 1947. The much larger Boeing B-52 became operational in 1955 and it is still in service to this day. These airplanes formed the backbone of our nuclear strategic force and maintained the strategic deterrent well into the 1960's.

At the same time, supersonic flight was achieved by small experimental aircraft designed for that purpose. The "sound barrier" was broken for the first time (on October 14, 1947) in level flight by U.S. Air Force Brigadier General Charles Yeager flying the rocket powered Bell X-1, the first of the famous X-series of experimental aircraft. These airplanes were built during the late 1940's and the 1950's and were developed under a joint program by the NACA and the U.S. Air Force—another example of the pervasive technical influence of the NACA. The last of the X-series airplanes was the famous X-15, which was a true rocket airplane. The North American Aviation X-15 was the first manned vehicle to go into space, reaching an altitude of over 67 miles (354,200 feet) during a flight by NASA Chief Test Pilot Joseph A. Walker on August 22, 1963. The X-15 had most of the features of the Space Shuttle and was in a real sense the prototype aircraft for the Shuttle. It is no accident that Neil Armstrong, the first human to set foot on the moon, was an X-15 pilot. I should point out that the first rocket aircraft was actually developed by the Germans, the Messerschmitt ME-163, in 1944. It was an important technical step, but it was clearly not developed further at the time because the Germans were so close to defeat in World War II.

The commercial impact of jet aviation was, if anything, more important than the military impact. Once operational experience was gained with the Boeing B-47's, Boeing B-52's and the tankers, the Boeing KC-135's that made these bombers truly intercontinental, commercial operations were also started. Starting with the Boeing 707, a direct modification of the Boeing KC-135, commercial operations burgeoned. In 1959, the last year before large jet aircraft came into service, U.S. air carriers flew 36.3 billion passenger miles. In 1982, they flew 259.03 billion passenger miles which is an enormous expansion by any measure. The technology of the large passenger jet has made world travel commonplace. A single Boeing 747 carries more people back and forth across the Atlantic in a season than the "Queen Mary" did in her heyday, and the airplane can do so at one tenth of the cost.

World travel is now commonplace, and there is no doubt that the movement of millions of people around the world has had profound political effects. In many regions of the world, national boundaries have essentially disappeared because of air travel. This is particularly true today in Western Europe where national boundaries still exist but where the people themselves behave as if they did not. Moslems all over the world, for example, make their traditional pilgrimages to Mecca by jet transport. Many millions have made trips never before possible, and this has clearly expanded human horizons and the human imagination. Today's young people may be the first truly international generation. All of this has had incalculable political effects that are now only dimly perceived. It is not even clear whether the easy travel we enjoy today will in the end be beneficial or whether it will simply exacerbate the differences between people that have always existed. What is certain is that all of this is due to the technology that flowed from the jet turbine engine and the all metal airplane, and, furthermore, most of this is due to American technology. Go to any international airport outside the Communist area and you will find aircraft bearing the flags of all nations. The vast majority of these aircraft were built in Seattle or in Los Angeles or some other place in the United States and the engines came from Lynn, Massachusetts, or Hartford, Connecticut, as well. This exercise of American influence may be subliminal, but it is all-pervasive and we should not forget it. More tangibly, aeronautical products account for something like $20 billion worth of exports per year, second only to agricultural products. This also is a result of our dominant position in aeronautical technology.

It would be a mistake here not to mention the important influence of American military aircraft as well. We have already talked about the strategic bombers but there are other military aircraft that need to be considered. Two examples illustrate this point: In 1978, a bitter civil war was raging in what was then called Rhodesia. An agreement was reached to hold elections and the British provided a peace-keeping force to oversee the elections. This force was brought in and supplied by U.S. Air Force Lockheed C-141 transports. It is doubtful whether a more or less satisfactory political solution in Rhodesia-Zimbabwe could have been found without the aid of these very capable aircraft. Another example is an incident that occurred in 1982: When Israel invaded Lebanon to destroy the Palestine Liberation Organization's military strongholds in the southern part of that unhappy nation, an air battle was fought by Israel with the Syrian Air Force. In a matter of hours, over seventy modern Russian-built Syrian aircraft were destroyed by American-built, Israeli flown McDonnell Douglas F-15's and General Dynamics F-16's. The Israelis did not lose a single aircraft, demonstrating beyond all doubt the superiority of modern American military airplanes.

The jet age can truly be called an American creation, and the full impact of what this new technology will bring is still to be assessed. It is not too early, however, to draw at least some conclusions. One is that we have made world travel commonplace, and this has provided experiences for hundreds of millions of people that were simply not available for prior generations. Will this make it easier to conduct a foreign policy aimed at maintaining a stable world? It is possible at least to hope that this is true, but we will only know this once the generation that has benefitted from this circumstance assumes full political leadership. Another is that the jet airplane has made it possible to Project military power anywhere in the world. In many instances this has contributed to stability—the Berlin Airlift, the situation in Rhodesia-Zimbabwe, the stabilization of the Congo and in a number of other places as well. We must continue to use this far-reaching capability to maintain stability and world peace. There is no doubt that the opportunity is there (Reference 3).

(5) **The Enterprise in Space**

The years following World War II were crucial in the development of seminal ideas. The great mathematician and public servant, Dr. John von Neumann, saw in 1945 that the existence of nuclear weapons and the emerging technology of large liquid fueled rockets would lead to the creation what he called intercontinental artillery. Von Neumann saw that the great intercontinental bombers were to some extent a stopgap and that eventually the Intercontinental Ballistic Missile would be the centerpiece of the nation's nuclear strategic forces. The development of these rockets—based on the principles already proved out by the Germans with their V-2's—happened in a remarkably short time. A decade after the end of World War II, the first Intercontinental Ballistic Missiles (ICBM's) were put into the field. The Russians were not far behind, and, because their nuclear warhead technology was more primitive than ours, they actually built larger rockets than we did during that period because their less efficient nuclear weapons were heavier. It was not a great step from the ICBM to space. A rocket capable of throwing an 8,000 pound warhead halfway around the world could also put an artificial satellite into earth orbit. Thus, the "Enterprise in Space" started with the development of the ICBM.

In 1946, a really remarkable paper was published by the RAND Corportation (the principal authors of this paper were Francis H. Clauser, David T. Griggs, and Louis

Ridenour) (Reference 4) in which almost all of the things that have been done in space for the past forty years were foreseen. These things ranged from the creation of communication satellites to the exploration of the moon and the planets in our solar system. The paper started with the premise that the ICBM's could easily be modified to become space boosters. Everything followed from this basic idea. The authors of the RAND paper also foresaw the political and symbolic importance of making the first steps into space. It is unfortunate that the American political leadership in those years did not believe this point.

On October 7, 1957, the Russians startled the world—and shocked the American people—by launching the world's first artificial satellite, Sputnik I. Not only that, two months later, they launched a large scientific research satellite that weighed well over a ton, and with these events the race into space was on. The political leadership of the United States had taken the position that earth satellites were purely scientific instruments and, therefore, the American program to orbit an earth satellite (Project Vanguard) was carried out at a leisurely pace driven by the scientific requirements of an international scientific program, the International Geophysical year. Once the Russians orbited Sputnik, resources on the American side were quickly mobilized, and, on January 31, 1958, less than four months after the Russian launch, the first successful American built satellite (Explorer I) was placed into earth orbit. That the United States was able to respond so quickly was due primarily to the foresight of Dr. Wernher von Braun and his collaborators—the wartime developers of the V-2 rocket. They were brought to this country after the war to continue their research and development work on large military rockets. Before 1957, von Braun's group was prohibited from working on earth satellites and their launch vehicles. With great technical virtuosity and at considerable bureaucratic risk, they put together the rocket and, with the help of the Jet Propulsion Laboratory, the payloads for Explorer I—even before the Russians launched Sputnik I—anticipating that their hardware would eventually be needed and used.

What was much more important than the technical success of Explorer I was that in 1958, stung by the Russian space achievements, the United States in short order created the institutions that would rapidly permit the United States to recapture and then to keep the lead in the human race's "Enterprise in Space." These institutional arrangements were founded on the National Advisory Committee for Aeronautics (NACA) which so successfully provided the basic technology to maintain American leadership in aviation. In the fall of 1958, a new organization—the National Aeronautics and Space Administration (NASA)—was created. The new organization was given a very broad charter to maintain American leadership in space and aeronautics. Recognizing the political and symbolic importance of space operations, NASA was created specifically as a civilian organization which would conduct its activities in a completely open manner under the full glare of publicity. Furthermore, the law under which NASA operates specifies that those space operations important to the national security would be conducted by the Department of Defense.

The success and the impact of American space operations have been largely the result of this important and unique political arrangement. Another important feature of NASA is that the traditional technical excellence of the NACA was maintained in NASA. The old NACA formed the bedrock on which the new NASA was built. In addition to the NACA, several elements operated up to that time by the U.S. Army (the Ballistic Missil Organization at the Redstone Arsenal in Alabama and the Jet Proppulsion Laboratory in Pasadena) and the U.S. Navy (the Naval Research Laboratory, a portion of which later was split off to become the Goddard Space Flight Center) with space related activities were transferred to the new agency. Once these arrangements were completed, the United States was ready to recapture the leadership in space operations.

(6) The Race to the Moon

Five months after assuming office as President in 1961, John F. Kennedy set a goal for the nation to put a man on the moon and bring him back safely before the year 1970 (Speech by President Kennedy, May 25, 1961). There is no doubt that the President's decision was motivated by important political and foreign policy considerations. The Russian feat of orbiting the first man, Yuri Gagarin, in April of 1961 was clearly a major stimulus for the President's move. By that time, it was clear that visible technical achievements in space technology were widely accepted as a measure of "national competence," if you will, and, in that sense, it was important for the U.S. to recapture the lead from Soviet Russia.

President Kennedy also recognized that, in addition to the influence on foreign policy, there were domestic advantages as well. The trip to the moon became something around which certain major elements of American technology could be focused. An interesting case in point is the electronic control system that was developed for the Lunar Excursion Module (LEM). This was the first time a completely "fly-by-wire" system was used, and it has now been incorporated into advanced military aircraft such as the F-16 and will undoubtedly be applied to the next generation of civil aircraft as well.

So, the race to the moon was on, and there should be no doubt that it was a race. The Russians deny it now, but they did make a major effort to go to the moon and to get there before the Apollo astronauts. The Russians cancelled their effort to put a man on the moon shortly after they had several costly launch vehicle failures in 1969. The landing of Apollo 11 on the moon in 1969 clearly reestablished American leadership in space operations, and it is a lead that we have not relinquished since that time. There is no doubt that Apollo had a profound impact on the rest of the world and gave strong encouragement to our friends around the world during a period in American history when it seemed that we had lost our way and our collective will. It was the one shining event in a decade which started with great promise but was characterized ultimately mostly by failure. I remember visiting Yugoslavia during one of the Apollo missions, and I was

amazed by cheers we received everywhere when people discovered that we
Americans. There is no doubt that the vast majority of the people we met were
that we had bested the Russians.

Two important things were done subsequent to the Apollo program using hardware that was developed for Apollo, one technical and the other political. The world's first orbiting space laboratory—Skylab—was launched in 1973 and was subsequently visited three times by astronaut crews. Many new things were learned about the behavior of people in space and about some things that can be done in space related to processing and manufacturing. These will be of increasing importance as the Shuttle program matures and as we start to plan for a permanent Space Station.

The other project was Apollo-Soyuz. Both President Nixon and Secretary of State Kissinger understood the popular appeal of achievements in space operations. Accordingly, they looked for a space project to underscore the policy of "detente" with Soviet Russia that they were pursuing at the time. When approached with this problem, NASA proposed a link-up in space during which an American Apollo module and support unit would dock with a Russian Soyuz spacecraft. Three American astronauts would meet two Russian cosmonauts in space and shake hands, thus symbolizing the Nixon-Kissinger policy. The Apollo-Soyuz project was successfully executed in 1975. It is not clear what effect Apollo-Soyuz actually had because the political imperatives that existed in 1971 when the project was conceived no longer really applied in 1975. What is important is that at the highest national level, the potential symbolic foreign policy importance of space operations was clearly recognized (Reference 5).

(7) Space Operations and the Advancement of Science

The authors of the 1946 RAND report (Reference 4) foresaw that space operations would lead to many new scientific discoveries of great significance. Their expectations have been fully justified. Starting with the lunar orbiters and the Surveyors in the early

1960's, we have made close fly-bys or landings on all the planets in the solar system except Uranus, Neptune, and Pluto. We have sent two spacecraft (Pioneer 10 and Voyager II) on journeys out of the solar system. Perhaps the things we have done in space-based astronomy will be even more important and spectacular than what has been done in planetary exploration. Space-based telescopes have probed the outer reaches of the universe and have brought us significantly closer to understanding some of the most fundamental phenomena in cosmology and how these might be related to the ultimate structure of matter.

There is no doubt that the U.S. enjoys a commanding lead over our principal competitors, the Russians, in space science. This is very important from a cultural viewpoint because we can only really aspire to being a great nation if we value science. Our scientific work in space has important international implications, which is our major concern here. Almost all of the space science programs executed by the United States have had participants from other nations. Because of the open nature of the American space program, these international collaborative efforts can be easily arranged and they have been very fruitful. An international network of scientists exists that has come to rely on the U.S. for providing opportunities to perform research in space. While this group is not necessarily important in day-to-day questions involving foreign affairs, many are influential in the international scientific community. As such, they do play a role in helping to provide the intellectual atmosphere in which foreign policy is conducted.

As important as this scientific work has been, especially in providing new horizons for the human imagination, scientific research based on looking at the earth from space may be even more important. For the first time we really understand global weather patterns, and we have actually been able to construct mathematical models of the earth's atmosphere that have great value in making long-range weather forecasts. Observation satellites such as Landsat have yielded absolutely remarkable results. We have been able to look at trends, such as deforestation for example, on a comprehensive global basis and we have been able to assess the long-term consequences of these trends. We have made worldwide crop assessments routine using Landsat data, and we have provided accurate maps of large regions of the world—such as the Amazon Basin—where none existed before. The ground data receiving stations for the Landsat system are located all over the world, and many nations participate with the United States in the Landsat program. Twelve countries now receive data directly from Landsat through their own ground stations (China is establishing one), and many others participate with the U.S. in research programs that are of particular interest to them. The U.N. Environmental Program (UNEP) uses the data from the Landsat system as a primary source of information for the evaluations which they make. In addition to Landsat, the United States has flown or now operates a series of more specialized scientific satellites designed to observe certain features of the earth's surface in much greater detail. Examples of these are Seasat, which was designed to observe the ocean, and GEOS, which permits us to make very precise determinations of the shape of the geoid. The latter is particularly important because it permits us to make very accurate measurements of the motion of one part of the earth's surface with respect to another, thus permitting verification of the theory of plate tectonics and continental drift. There is reason to hope that work done with this satellite will permit us to make progress toward the prediction of earthquakes.

It is obvious that all of these things have important international implications. While the U.S. has been a leader in developing the necessary international arrangements to use the information obtained from earth observation satellites, there has been considerable ambiguity within successive American Administrations regarding the proper government role in the development of earth observation satellites. Some have advocated that the NASA-developed and NOAA-operated earth observation satellites be turned over to the private sector for operation at a profit since the government has no business in the operation of these satellites beyond the research phase. There are formidable financial and institutional barriers in the way of achieving this objective, and it might be worthwhile to explore the possibility of using the impact on our foreign relations to keep these programs going until we sort out our internal problems. The failure to develop a proper rationale for the operation of earth observation satellites by the United States will inevitably lead to a situation in which other spacefaring nations such as Russia, France, and possibly Japan will take over the business. The United States cannot permit this to happen, and the very positive effect that earth observation data sharing with other nations has had should be reason enough to keep these activities going. It is to be hoped that a broader look at the whole question of earth observations, including those performed for the purpose of national security, will lead to a better understanding of the vital role that the United States can and should play in this very important area (Reference 6).

(8) Space Operations and the National Security

The Russians remain the principal adversaries of the United States in the world. Russia has a closed society which operates under very strict rules regarding what foreigners can and cannot learn. All of the information media are under strict government control, and all mail leaving the country is strictly censored. Travel for foreigners within Russia is heavily restricted and visitors are closely watched. The Russians have a dangerous paranoia about national sovereignty and, unfortunately, they act accordingly. In spite of all this, world security and stability require that we have at least some minimal information about what the Russians are doing, and we have applied aerospace technology for this purpose for many years. In the early 1950's, it was extremely important to learn what the Russians were doing in nuclear weapons technology. Accordingly, an aircraft was designed and built that could operate at extremely high altitudes which were then beyond the range of surface-to-air missiles and above the maximum ceiling of interceptor aircraft. The result of this effort was the famous Lockheed U-2 reconnaissance aircraft which was developed by Kelly Johnson in a major technical tour de force. Overflying Russia with a U-2 aircraft was a violation of Russian sovereignty, and it was expected that they would bend every effort to find means to shoot down a U-2. Eventually, they accomplished this objective in 1960, and, although U-2's and their companion reconnaissance aircraft, the Lockheed SR-71's, are still in active service today, they are operated in such a way that there are no violations of Russian airspace.

The shooting down of Gary Powers' U-2 coincided in time roughly with the rapid growth of space operations. It was natural at the time to see whether some of the functions performed by the U-2's and the SR-71's could also be performed by earth orbiting satellites. In that way, the overflight problem could be avoided at least until the capability to shoot down satellites existed. Accordingly, a series of highly classified observation satellites were developed for this purpose, and these satellites have assumed an ever more important role as the years have passed. Perhaps the most important function carried out by these observation satellites is the monitoring and the verification of arms control agreements. There is not much doubt that such agreements would not be possible unless they can be verified. In the 1972 strategic arms control agreement that we negotiated with the Russians (SALT I), there is a provision that neither side shall interfere with the other's "national technical means of verification." In 1978, President Carter revealed for the first time that these "national technical means" were, in fact, photo reconnaissance satellites operated for the purpose of arms control verification. The satellites we have developed for this purpose greatly reduce the uncertainty that our political leaders face in making decisions and, in that sense, the existence of these satellite systems contributes to world stability and peace (Reference 7).

In addition to the surveillance satellites, the military establishment also operates weather observation satellites, communications satellites, and satellites designed to provide warning of a major strategic missile attack. These are all extremely important functions, and it is important to recognize that none of this would be possible without the vigorous development of aerospace technology by the United States.

There is not much doubt that the Russians are aware of the importance of our space operations related to the national security. Since 1972, the Russians have been testing a system designed to shoot down our satellites—their so-called ASAT, or anti-satellite system. While their system is relatively primitive from a technical viewpoint, it is capable of destroying satellites in relatively low earth orbits. It is also important to recognize the Russian lead in this technology—at the present time, the United States does not possess an anti-satellite capability. Why did the Russians go to the trouble to develop an anti-satellite system and why haven't we? We do not know precisely, of course, but we can speculate. They know that our satellites are very important to us because of the closed nature of their society. On the other hand, their surveillance satellites are not nearly as important to them because they have other ways of gaining information about what we are doing since we have an open society. It was therefore felt less worthwhile for us to make the investment to produce an anti-satellite system, and the asymmetry that exists today in this capability resulted.

All of this led to renewed concerns with respect to the deployment of weapons in space. Russia and the United States have several agreements that limit the deployment of weapons in space. We have agreed not to deploy weapons of mass destruction in space, and we have other pacts that limit certain space operations in other areas (Reference 3). Early in his Administration, President Carter became concerned about Russian anti-satellite tests and proposed to President Brezhnev that Russia and the United States initiate negotiations with a view toward a treaty to eliminate anti-satellite weapons. Negotiations were carried out for about two years, but they were not successful. In the absence of an American anti-satellite capability, the Russians had no incentive to negotiate seriously, and they did not do so. In fact, they continued their anti-satellite test program during the negotiations. The negotiations were terminated when it bacame obvious that no progress would be made. One result of the unsuccessful talks is that the United States is now well on the way toward the development of an anti-satellite capability which will provide important leverage should negotiations to control anti-satellite weapons be resumed.

On March 23, 1983, President Reagan made a very remarkable speech. He said that progress in technology was such that the time had come to think seriously about developing a defense against ballistic missiles. There is no doubt that such a development would be a far-reaching step that would eventually lead to profound changes in the strategic balance. For almost 40 years, what we call strategic stability has been maintained by strategic nuclear forces operated under the doctrine of "Mutually Assured Destruction" (MAD). The essential idea is that each of the two superpowers possesses nuclear forces deployed in such a way that the forces can survive a surprise attack from the other. If this condition can be preserved, then the doctrine of "Mutually Assured Destruction" works. Each side is deterred from attacking the other because even if the attack succeeds, the destruction of the attacker is assured. What the President recognized is that, in the long run, it probably will not be technically feasible to deploy nuclear forces in such a way that they can survive a surprise attack. Therefore, new steps must be taken to maintain strategic stability, and the application of new techniques is necessary to accomplish that end. These new technologies include upgraded "smart" missiles that can detect and then home in on incoming ballistic warheads to hit and destroy them, new directed energy weapons that can be based in space to hit the attacking ICBM's almost anywhere in their trajectories, and new surveillance systems that will provide the necessary data to orchestrate the defense. All of this is within the realm of technical possibility, and the President has called for the development of a technical program that will lead to the creation of such a defensive system by the end of this century.

In the near term, two kinds of defensive systems seem to be feasible, and both of these do not require very large extrapolations of current technology. One is to build an anti-ballistic missile system designed to defend fixed intercontinental ballistic missiles in their silos. Sensor and guidance systems are now sufficiently good that such antimissile missiles can actually hit incoming nuclear armed warheads directly thus requiring no explosive charge to destroy their targets. This is called "kinetic energy kill" and it makes antiballistic missile systems feasible today. Fifteen years ago, when a great public debate was carried out over the question of defense against ballistic missiles, the antimissile systems of that day (1969) required nuclear warheads to kill the incoming missiles. It was judged at the time, correctly, I believe, that such a system would be impractical because of the large collateral damage that the defender's nuclear explosions might cause. Consequently, no serious deployments of military value were made.

An antiballistic missile system with non-nuclear kinetic energy kill warheads does not have the drawbacks of the systems considered a decade and a half ago. Even if such a system were only fifty percent effective it would have military value because it would in essence reduce the number of warheads available to a potential attacker for destroying the ballistic missile force of the adversary. The deployment of such a system--provided that it is "leaky"—would act as a deterrent to a potential attacker because the attacker can now no longer be certain that he can destroy the intercontinental ballistic missile force of the defender. Thus, such a system would make it possible to maintain the doctrine of mutually assured destruction for a while longer until more "perfect" systems are developed and deployed.

Another interesting idea that has been considered for well over a decade now is to develop laser armed aircraft that could patrol the ocean off our shores and shoot down submarine launched ballistic missiles in the boost phase of their trajectories. The Air Force has recently demonstrated that it is feasible to shoot down fast moving missiles with a high intensity laser mounted on a large jet transport. Such a laser carried by a Boeing KC-135 has destroyed five air-launched "Sidewinder" missiles fired in rapid succession. By a reasonable extension of this technology, it should be possible to develop lasers that can shoot down submarine launched ballistic missiles at ranges that are sufficiently large so that the number of aircraft on patrol can be kept reasonable small. It is important to hit the submarine launched missiles in the boost phase because they are easy to detect and also relatively "soft" to the laser damage mechanisms.

- The deployment of a force of aircraft that could shoot down submarine launched ballistic missiles would have important military value. The primary effect of such a deployment would be to force the Russians to move their missile carrying submarines away from our shores and out into the open ocean. Such a move would have the effect of lengthening the flight times of their missiles from a few minutes to the same times required for land-based missiles starting from the Eurasian continent. Thus, the aircraft deployment contemplated here would reduce the danger of a surprise attack on very short notice on our coastal population centers. The ability to conduct such a "short notice" surprise attack—a bolt out of the blue, if you will—is considered destabilizing under the doctrine of mutually assured destruction. The capability to conduct such an attack might provoke the potential victim to launch a pre-emptive first strike and this destroys the balance. Keeping the Russian submarines off our shores to prevent "short notice" attacks with depressed trajectory missiles would, therefore, increase stability. Thus, the two systems that could be deployed in the near term—say in the next ten to fifteen years—would actually have the effect of preserving the nuclear balance of forces based on the doctrine of mutually assured destruction (Reference 8).

In the longer term however, it should become possible to build more nearly "perfect" defensive systems by deploying various anti-missile weapons on space based platforms. Using such methods, a "layered" system could be built that might prevent more than 99% of the warheads launched by a potential attacker from reaching their targets. Such a system would indeed change the military doctrines under which the nuclear forces of the world are deployed. A situation would be created in which deterrence based on the fear of assured destruction of an attacker can no longer be sustained. It is difficult to make any really firm statements about the time scale on which the deployment of such a system could be achieved. My own guess is that by the middle of the next century a defensive system could be in place that would make it necessary to change the doctrine of mutually assured destruction. To achieve this objective, the necessary research and development work must be started now (Reference 9).

There are very good reasons to believe that all of these things can eventually be done, and it is, therefore, extremely important to start now to think through the political and foreign policy implications of the existence of such defensive systems. There is one particularly important point that needs to be considered. It is very likely that at least some defensive systems can be built without the deployment of any nuclear warheads. Therefore, "non-nuclear" powers such as Japan, Germany, Israel, and others who have the technical capability might also deploy effective antiballistic missile systems. It is quite possible, therefore, that these nations, if they deploy such systems, could make them much less dependent on the United States for defense than they are today.

The President's strategic defense initiative is probably the most far-reaching step he has taken during his entire Administration. It marks a watershed in strategic thinking because the President has recognized explicitly that the doctrine of "Mutually Assured Destruction" may not be technically supportable in the long run, and he has challenged the American technical community to develop defensive systems that will hopefully create a new and stable strategic balance. Concern over the President's move has been expressed in many quarters, but, once the issues are clearly understood, I believe people will realize that we have no choice but to go ahead with the development of defensive systems. We know that the Russians are already working on defensive systems indicating that they have also recognized that the era of "Mutually Assured Destruction" is slowly drawing to a close. The coming decade will be dangerous—as we start the shift from one nuclear strategic concept to another—but there is no doubt that it will be done. We cannot afford to let other nations—particularly the Russians—exceed us in the capability to field strategic defensive systems. Instability will surely result if we let that happen. The best and only course is the one the President has suggested, and that is to apply our great strength in aerospace technology to create the strategic defensive system that the President has in mind (Reference 10).

(9) Space Operations and the Advancement of Technology-Commercial Implications

There are two important issues that need to be examined when looking at technology and its commercial implications. One is the direct application of space technology to commercial enterprises and the other is the list of technical "spin-offs" that has resulted from the move into space. One of the important predictions of the 1946 RAND report was that satellites would be used to establish a worldwide communications network. Less than forty years later, this objective has been accomplished. Not only that, the satellite-based communications industry is very profitable, and, because of our technological leadership, the United States still dominates this important field. The commercial communications satellite industry was established in 1962 when a government-sponsored corporation—COMSAT—was established to see what could be done to exploit the commercial potential of communications satellites.

At about the same time, NASA launched the first experimental communications satellite into geosynchronous orbit. These NASA satellites, the Applications Technology Satellites, became the prototypes for the subsequently developed geosynchronous commercial communications satellites that now form the backbone of our communications satellite system. In this case, NASA was providing support for the communications satellite industry much the same way NASA (and earlier the NACA) provides support for the aeronautical industry. The development of satellite communications has had very important international implications as well. In 1964, the United States led in the formulation of the INTELSAT (International Telecommunications

Satellite) organization. The organization was formally established in 1973, and, at the present time, 108 nations are members of INTELSAT and use the services of the organization. The United States is still the dominant member of INTELSAT because of our continuing technical leadership—for example, the INTELSAT satellites are still manufactured by the United States and put into orbit by mostly American launch vehicles. However, this situation is changing. The French now have an operational launch vehicle—the Ariane—that is capable of placing commercial communications satellites into geosynchronous orbit. Furthermore, both the Europeans and the Japanese have a growing communications satellite industry which is becoming rapidly competitive with what is being done in the United States.

In order to maintain the competitive edge we now have in communications, NASA, in collaboration with the communications satellite industry, is proposing the development of a new program, the Advanced Communications Technology Satellite (ACTS) technology program. The latest technical advances, including operation at higher frequencies, rapid beam switching, and onboard data processing, will be incorporated on satellites that employ this new technology. Hopefully, the new technologies that will be incorporated into the next generation of communications satellites will maintain the technical lead enjoyed by American satellites in this very important area (Reference 11).

At the present time, satellite-based communications systems constitute the only example of a successful commercial enterprise that depends on operations in space. There are other possibilities on the horizon, but so far they are only a gleam in the eye. Perhaps the most fascinating of these is the possibility of using the zero gravity environment in an orbiting vehicle to manufacture certain things that cannot be made in the gravity field on the earth's surface. The best candidates for such manufacturing operations are those in which small quantities of very special, high value materials are produced, thus minimizing the weight that has to be carried into orbit. The first Spacelab flight, executed in November 1983, was very encouraging in this respect. This criterion applies very well to the biological materials that are produced in the Continuous Flow Electrophoresis apparatus that has been flown on five Space Shuttle missions. During the course of these flights, it has been demonstrated that there is an improvement in the ability to separate the materials of interest by something like a factor of 5,000 over what can be done on the ground. It is too early to tell yet whether this factor is enough to assure a profitable operation. A heartening sign, however, is that the development work on the instrument has been funded by private capital under a joint venture agreement between a pharmaceutical house (Johnson & Johnson) and an aerospace company (McDonnell Douglas).

In addition to direct commercial applications of the space operations cited in the previous paragraphs, there is the matter of "spin-off." This term usually refers to the application of technology originally developed for the space program to other purposes. Perhaps the classic example is solid state electronics. The development of the first transistors in 1948 coincided with the effort to create the first ICBMs. It was recognized immediately that electronic control systems based on the transistor would be much lighter in weight and would consume much less power than conventional control systems based on vacuum tube technology. Thus, the ICBM program, and later the space program, provided essentially unlimited financial support for the early development of transistor-based electronics. The consequences—economic and social—of all this are well known. The revolution in communications and information processing would have been impossible without the transistor, and that transistor technology would not have developed as quickly without the spur provided by both the military and civilian space programs.

Another very important area in which there have been significant technological "spin-offs" is in the field of materials. Space operations put special premium on light weight (in structures), high temperature resistant (in engines), and fire resistant (for interiors) materials. A whole new generation of structural metals, alloys and synthetics has been developed that has found applications in every nook and cranny of the economy.

These are only two examples and there are many more. Attempts have been made to quantify the economic impact of these "spin-offs." The pessimists say that it would have been cheaper to develop all of these products for their own sake rather than to get them as "spin-offs" from other efforts. Those of us who know how the development process works know that this is simply not true. Genuine advances are made only when really tough technical requirements are set, and most of the products derived from "spin-offs" would not exist because normal commercial requirements are not that stringent. The optimists, on the other hand, make a different calculation. In her book, "The Political Economy of the Space Program," Mary A. Holman estimates that for every federal dollar invested in the American space program, fourteen have been returned to the general economy. The truth is probably somewhere in between and that is good enough (Reference 12).

(10) The Space Shuttle and the Permanent Presence in Space

About one year before the successful landing on the moon on July 20, 1969, then NASA Administrator Thomas O. Paine initiated a series of studies aimed at developing what was then called the "Post-Apollo Program" for NASA. These studies were carried out by several groups (the Space Task Group, as well as several internal NASA Committees), but a consensus emerged that the next step would involve somehow the construction of a permanent operating base in earth orbit—that is—a Space Station. It was also clear from these early considerations that if a substantial Space Station were built, then some kind of a reusable "Shuttle" vehicle would be necessary to keep the Station occupied and supplied. Thus, the concept of the reusable Space Shuttle was born. As things turned out, the political leadership at the time decided that not enough money was available to initiate both a Space Station program and a Shuttle program. Since the Space Shuttle was technically more difficult to develop than the Space Station, it was deemed to be the pacing item in the program, and so a decision was reached to build the Space Shuttle first. It was felt that the Space Station would come later once the Shuttle was in operation (Reference 13).

The Space Shuttle program was initiated in ~~February~~ January 1972 when President Nixon gave final approval to the Space Shuttle proposal developed by NASA. At the time, NASA promised to develop a reusable Spacel Shuttle launch vehicle based on the "stage-and-a-half principle" that would deliver a 65,000 pound payload to a 28.5^0 inclination orbit. NASA also said that the first flight would be carried out in 1978 and that the development cost would be something of the order of $6.5 billion in 1972 dollars. As it turned out, the "Columbia," the first Shuttle orbiter, flew for the first time in April 1981; the total development cost was approximately $9.0 billion in 1972 dollars; and the vehicle has the capacity today to deliver about 60,000 pounds, although further payload improvements are to be expected. Even though the original cost, schedule and performance goals were not quite achieved, the Space Shuttle program has definitely been a success by any standard of measurement.

In addition to the technical success, the Shuttle has been a political success very much beyond the expectations of those of us who were involved in the development program. The Shuttle has attracted much more public attention both in this country and abroad than we originally expected. A good example of this is the trip to Europe made in May and June of 1983 by the "Enterprise" and the Boeing 747 Shuttle Carrier Aircraft. Well over two million people went to see the "Enterprise" at the four airports—Bonn-Cologne, Paris, Rome and London—where the Shuttle was on exhibit. The news media in all of the places that the Shuttle visited provided very positive coverage of the event. There is no question that the impact of all this has been extremely positive for the United States. There is no question that space exploration still has a very basic appeal to people all over the world.

There are still a number of unanswered questions regarding the ultimate operation of the Space Shuttle in spite of the great success that the program has enjoyed. Will we depend exclusively on the Shuttle or should we retain and/or develop unmanned launch vehicles? How should the Shuttle eventually be operated? What can be done to make certain that safety of operation of the system is maintained and improved? The last question is particularly important precisely because of the political popularity of the Shuttle along with the other reasons for maintaining safety of flight. It is of the utmost importance that the effort to preserve safety of flight remain the first priority in the Space Shuttle program as we approach the operational era of the Shuttle.

The development of the Space Shuttle has resulted in the creation of a number of new hardware components on which a new generation of space launch vehicles can be based. The large solid rocket boosters can be modified so that they can replace most of the expendable launch vehicles in service today. Furthermore, launch vehicles based on the new technology would be much less costly than the expendable launch vehicles currently in use. In addition, the Space Shuttle Main Engine could also be used in combination with the solid rocket booster to develop very large launch vehicles that would have the capability of putting payloads up to 500,000 pounds in near earth orbit.

Now that the Space Shuttle development program is near completion, the next step is to initiate the development of the Space Station. In his State of the Union message, delivered on January 25, 1984, President Reagan made the commitment to construct a permanently manned Space Station in near earth orbit (Reference 14). The President called for the development and the deployment of such a Space Station within the next decade and, recognizing the important international impact of American efforts in space, he called on our friends and allies around the world to collaborate with us in taking this far reaching step. The essential purpose of the Space Station is to provide an operating base in space to support the activities that will be carried out in the future. The Space Shuttle will change in a fundamental way business is done in space and it is this circumstance that will eventually lead to the construction of a Space Station.

why not cite Presidential Documents?

Perhaps the most important change is that, in the future, satellites in near earth orbit can be repaired and refurbished. Instead of deactivating or deorbiting satellites after their "useful" life is over as we do now, satellites will become permanent facilities in orbit because with the Shuttle it will become possible to resupply and refurbish satellites on-orbit. The Space Telescope, for example, has been designed from the very start to be such a "permanent facility." The plan is to revisit the telescope periodically with the Shuttle and to perform various maintenance and refurbishment functions. For example, the focal plane of the telescope has been designed in such a way that the detecting instruments can be replaced with new ones if and when better technology becomes available. It will therefore be possible to continually upgrade the performance of the Space Telescope.

It is very likely that the design of many satellites will follow the pattern set by the Space Telescope and that in a decade or so there will be a significant number of "permanent facilities" of this kind in near earth orbit. Once this happens, there will come a time when it will be more convenient (and probably less expensive) to have an operating base in earth orbit for the conduct of replenishment and refurbishment missions. The cost-effectiveness calculation cannot yet be made with any precision, but there is clearly some critical number of satellites above which the cost of making a trip from the earth each time a refurbishment operation is carried out exceeds the investment necessary to build a Space Station. The Space Station also would be extremely useful as a facility at which large space structures can be assembled. There is every reason to believe that such structures will become very important as we deploy large antennas in geosynchronous orbit for direct broadcast satellites or large mirrors for improved light gathering power. In addition to the construction operations, manufacturing procedures of the kind described earlier in this section would benefit from a permanent Space Station.

Finally, and this is perhaps the most important point, the Space Station will become the staging base for other missions that we will want to perform in the future. It is probably not possible, for example, to do a manned planetary mission without having a staging base of the kind provided by the Space Station. Also, at some time or other, people will want to return to the moon, and if we wish to carry out sophisticated operations there, a staging base in earth orbit is required. The technical argument is quite simple: putting people on other planets and conducting significant operations on the moon requires the existence of "true" spaceships—that is—vehicles designed to fly in space. The only true manned spaceship that the United States has ever developed is the Lunar Excursion Module. All others, the rockets, the Mercury, Gemini, and Apollo capsules and, of course, the Shuttle itself are hybrids—that is—they are designed to fly both in space and in the atmosphere. The heat shields and the control surfaces that must be added put prohibitive weight penalties on these vehicles if, for example, a Shuttle flight to the moon and back is contemplated. The right way to accomplish the objective of putting significant payloads on the moon is not by using only the Shuttle but by transferring the payload from the Shuttle to a true spaceship at the orbital staging base (the Space Station) and then going on from there.

While all of the things that will be done with a Space Station are important, it would be a mistake to ignore the symbolic political value of the Space Station. The President recognized this point explicitly when he proposed the construction of a Space Station. He understands that a vital function of political leadership is to provide visions for the future and he clearly views the Space Station as such. There is every reason to believe that the Space Station will attract considerable public attention and, therefore, have value over and above the practical utility that has just been discussed. Furthermore, we have strong evidence that the political leaders of our allies feel the same way. NASA Administrator James M. Beggs has recently completed a trip to visit European (German, French, Italian and British) and Japanese political leaders to initiate the discussions that will lead to the collaborative effort that President Reagan has in mind. The response of the foreign leaders was enthusiastic, and there is no doubt that the nations they represent will make very important contributions to the Space Station program (Reference 15).

For all of these reasons, the Space Station is the next logical step for the "Enterprise in Space." Thus, in the coming years, the United States and its allies will begin the construction of a permanent Space Station to, as President Reagan put it in a speech on July 4, 1982, "exploit the potential of the Shuttle to establish a more permanent presence in space."

(11) Visions for the Future

What lies ahead in aerospace? What predictions can be made with relative safety and are there some surprises in store? In the preceding chapters, some of the nearer term plans and possibilities have been described in some detail. It might be worthwhile, therefore, to attempt a look a little farther into the future in order to try and define some things that can only be dimly perceived today. I recognize that I am taking some risk in doing this, but I cannot resist the temptation.

We now have an air transportation system that, in spite of some economic problems, is extremely efficient when it comes to transporting people and goods over stage lengths in excess of 500 miles. It is unlikely that a new technology will lead to changes that will improve what has come to be called the "long-haul" air transportation system by an order of magnitude. Improvements will be evolutionary and substantial but not earth shaking. The interesting question is whether there is room for some revolutionary change in some other part of the airline business. One of the really significant changes that was brought about by the deregulation of the airlines in 1978 is the growth of commuter or "short-haul" airlines. These airlines serve a market centered on the smaller cities that are no longer served by major carriers. They use small, inexpensive turboprop aircraft to provide this service. It is an interesting fact that most of the aircraft operated by the commuter airlines today are of foreign manufacture (the De Havilland DH-7, the De Havilland Twin Otter, the Shorts Skyvan, and others) primarily because American manufacturers felt that there was no market for these airplanes.

- Is there a chance that American manufacturers can recapture the commuter market through the application of new technology? If so, what must be done to achieve this objective? There is, I believe, a good chance that the new technology that might be very useful is that of the tilt-rotor VTOL airplane. These airplanes can take off vertically like helicopters using two large rotors mounted on the wingtips of the aircraft. Once off the ground, the rotors are tilted forward and they become the propellers of a more-or-less conventional airplane which can travel at 350 knots—over twice the speed of a conventional helicopter and without the severe vibrations that make helicopters very expensive to operate. A joint NASA-U.S. Army program that was executed during the 1970's resulted in the development of the Bell XV-15, an experimental tilt-rotor airplane. Two aircraft were built and have been thoroughly tested. Their performance exceeded original expectations. There is no doubt that a larger version of the XV-15 would be an excellent commuter aircraft. The VTOL feature of the airplane could have a very profound effect on airline service because it would, for the first time, make airlines—or at least the commuter airlines—independent of airport facilities. Application of tilt-rotor airplanes in this way might lead to the first true "air-bus" service (Reference 16).

What needs to be done to bring tilt-rotor airplanes into the commercial service envisioned here? It is possible, even likely, that the development of tilt-rotor airplanes will follow the pattern we have already seen in the case of the large multi-engine jet aircraft. The military has initiated a program, called JVX, with the objective of replacing the large troop-carrying helicopters used by the Marine Corps. A decision has been reached to use tilt-rotor technology for this purpose and to develop a relatively large—40,000 pounds gross weight—tilt-rotor airplane. There is good reason to believe that once these airplanes go into service, we will learn enough about the economics of operation and the technical maintenance and safety problems so that the aircraft can be put into commercial service with relatively low risk. There is a reasonable chance that we will see this development in the coming decade.

The VTOL principle will have other military applications in the future when applied to high performance aircraft. The British Harrier and the McDonnell Douglas AV-8B, which is a derivative of the Harrier, are examples. There are some advanced VTOL concepts under development that would ultimately be more efficient than the Harrier with its vectored thrust propulsion system. The importance of high performance VTOL combat aircraft is intimately linked to air base survivability. These airplanes will be developed with great urgency if we are ever forced to fight a war in which our major operational bases come under attack. It is a fact that the two major conflicts in which the U.S. has been involved since the end of World War II (Korea and Vietnam) were both fought under political ground rules that permitted our tactical air forces to operate from air bases that were treated as sanctuaries. Thus, the problem of dealing with air base survivability has not really been uppermost in the minds of senior Air Force people. Once this changes—and I think that it will—then high performance VTOL combat aircraft will be developed.

In addition to the things that I have mentioned, there are possibilities for the longer term that should be mentioned. Some people are thinking about transport aircraft that may be twice as large as the current Boeing 747's and Lockheed C-5A's. These would have a gross weight of the order of 1.5 million pounds and would, of course, have enormous range-payload capabilities. One of the intriguing possibilities that may become practical for aircraft of this size is the use of liquid hydrogen as fuel rather than the jet fuels currently in use. This could lead to a substantially higher propulsion efficiency and a new plateau of performance. There are also ideas for very high speed aircraft—above

Mach 5—that might be used for various purposes, but these are only in the planning stage. What is important is that there is no lack of bold ideas in the aeronautical community, and some of these will eventually come to fruition and see practical applications.

I have already described in some detail the things that can be expected to happen in space operations and space technology. Sometime in the next few years, the U.S. will build a permanent Space Station which will be used as a staging base for more ambitious operations. Sometime before the end of the century, people will return to the moon and a permanent base will be established. In the next few years, the first steps will be taken in the deployment of a working ballistic missile defense system based on the latest developments in aerospace technology. There is not much question that the existence of such a system will change the framework in which international politics are conducted. We must begin now to think through the implications and to imagine the kinds of alliances and relationships that we will want to create in a world that no longer can rely on the nuclear balance of terror to maintain stability. It is at least possible to imagine an era in which stability and peace are preserved by a space based complex of sensors, communications systems and weapons much the same way that stability was preserved by the deployment of nuclear weapons systems in the past forty years.

While all of this is extremely important, I would be amiss if I did not talk about science which is, after all, the cutting edge of understanding. In two years, we will launch the Space Telescope which will be, by any measure, the most important scientific instrument ever flown in space. What will we learn when we point the Space Telescope at the stars? We already have strong hints that the extremely energetic processes we see in quasars and pulsars have to do with entirely new states of matter that contain, in a more-or-less thermal equilibrium state, the particles we observe on earth only in very high energy collisions produced in high energy particle accelerators. It is quite possible that by combining the information we obtain from the Space Telescope and high energy accelerators we will be able to achieve Albert Einstein's dream of a unified field theory of forces. This theory would include the entire array of forces known in nature—from gravity that governs the motions of galaxies to the forces between the subnuclear particles we call quarks. Once this edifice is built, I am sure that there will come practical applications just as we saw extremely important applications come from Newton's unification of the work of Kepler and Galileo (Reference 17).

An observation that may ultimately be even more important will become possible with the Space Telescope. We will, for the first time, be able to establish with certainty whether there are other stars that have planets orbiting around them. There is good reason to believe that planetary systems such as the one that accompanies our sun are fairly common. If this point can be established, then the next question, of course, is to determine whether there are planets around other stars in the galaxy on which the phenomenon we call life has occurred. Are we alone in the universe? Is life unique? Or, is it common? These are obviously all questions of the highest importance and the things that we can do with the Space Telescope will begin to provide us with the first answers. It is obvious that the answers to questions of this kind will have profound philosophical and political implications. If the evidence mounts that we are alone, then that will influence the way we think about ourselves. On the other hand, if we do discover that we have companions elsewhere in the universe, then a different set of consequences will follow. Whatever happens—as Professor Philip Morrison has said—the possible outcomes boggle the mind (Reference 18).

I started this paper by asserting that aerospace is a peculiarly American enterprise. In closing, I want to return to this theme. The United States stands for progress and there is no doubt that we have made great progress in adding to human knowledge and well being by the application of aerospace technology. The United States stands for peace and it is clear that the application of aerospace technology has helped to maintain the precarious peace that exists in the world. Above all, the United States stands for freedom and this is perhaps where the contributions of aerospace technology have been most significant. We have provided the freedom to move and travel on a worldwide basis so that millions can now see the world for themselves. Most important of all, we have expanded human horizons and challenged the imaginations of millions around the world through the new adventure of space travel. In doing so, we reaffirmed our faith in the future and this is, ultimately, what freedom is all about.

References

(1) "Rockets Through Space," P. E. Cleator (Simon and Schuster, New York, 1936)

(2) "The Impact of Air Power," Eugene M. Emme, Editor (D. Van Nostrand Company, Inc., Princeton, 1959)

(3) "The Conquest of the Air," Frank Howard and Bill Gunston, (Random House, New York, 1972)

(4) "Preliminary Design of an Experimental World-Circling Spaceship," Project RAND Report SM-11827, May 2, 1946

(5) "Managing NASA in the Apollo Era," Arnold S. Levine, NASA SP-4102, (1982)

(6) "The World Environment 1972-1982," Martin W. Holdgate, Mohammed Kassas and Gilbert F. White, Editors (Tycooly International Publishing Ltd., Dublin, 1982)

(7) "The SALT Experience," Thomas W. Wolfe, (Ballinger Publishing Co., Cambridge, Mass., 1979)

(8) "Technology and the Strategic Balance," Hans Mark, Technology in Society, Vol. 4, pp15-32 (1982)

(9) "High Frontier," Daniel O. Graham (Tom Doherty Associates, Pinnacle Books, New York, 1983)

(10) "Arms Control and Space Technology," Hans Mark, Chapter 12 in "Nuclear Arms, Ethnics, Strategy, Politics," R. James Woolsey, Editor (ICS Press, San Francisco, 1984)

(11) "Communications Via Satellite," Delbert D. Smith, (A. W. Sijthoff, Boston, 1976)

(12) "The Political Economy of the Space Program," Mary A. Holman, (Pacific Books, Palo Alto, 1974)

(13) "The Space Shuttle-A Personal View," Hans Mark, J. Vac. Sci. Technol., Vol. 14, No.6, pp1243-1249, Nov./Dec. 1977

(14) "The Selling of the Space Station," M. Mitchell Waldrop, Science, Vol. 223, p793, February 24, 1984

(References continued)

(15) "Project Space Station," Brian O'Leary, (Stackpole Books, Harrisburg, Pennsylvania, 1983). See also the reports dated 1982 and 1983 of NASA's Space Station Task Force

(16) Civil Aviation Research and Development Policy Study, DOT TST-10-4, NASA SP 265, March 1971

(17) "Our Heritage-Our Future," Hans Mark, Interdisciplinary Science Reviews, Vol. 8, No.4, p297, December 1983

(18) "Life in the Universe," John Billingham, (MIT Press, Cambridge, 1979)